Science of the Total Environment 711 (2020) 134486

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Review

# The application of frameworks for measuring social vulnerability and resilience to geophysical hazards within developing countries: A systematic review and narrative synthesis

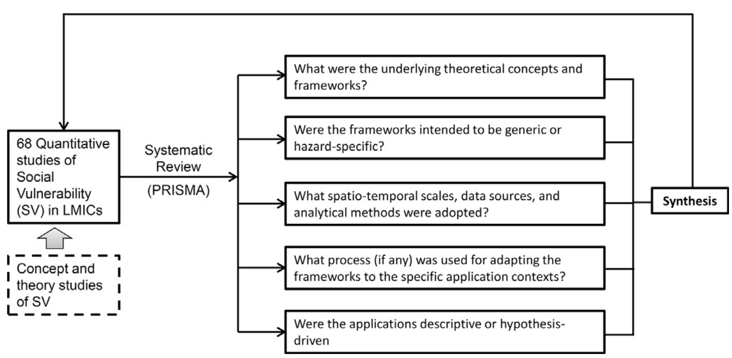
Jing Ran [a,b,c,*], Brian H MacGillivray [b], Yi Gong [b,d], Tristram C Hales [b,c]

[a] School of Architecture, Hunan University, Changsha, Hunan, China
[b] Sustainable Places Research Institute, Cardiff University, Cardiff, UK
[c] School of Earth and Ocean Science, Cardiff University, Cardiff, UK
[d] School of Medicine, Cardiff University, Cardiff, UK

## HIGHLIGHTS

- We conducted a systematic review of measuring social vulnerability in LMICs.
- Few papers measured changes in vulnerability or resilience over time.
- There was a lack of systematic efforts at validation.
- Many applications rely on existing frameworks with little adaptation to contexts.
- More hypothesis-driven studies are required.

## GRAPHICAL ABSTRACT




## ARTICLE INFO

*Article history:*
Received 8 April 2019
Received in revised form 14 September 2019
Accepted 15 September 2019
Available online 4 October 2019

Editor: Deyi Hou

*Keywords:*
Social vulnerability
Resilience
Measurement
Systematic literature review

## ABSTRACT

Quantifying and mapping resilience and social vulnerability is a widely used technique to support risk management, with recent years seeing a proliferation of applications across the Global South. To synthesise this emerging literature, we conducted a systematic review of applications of social vulnerability and resilience frameworks in Lower and Middle Income Countries (LMICs) using the PRISMA methodology. 2152 papers were extracted from 15 databases and then screened according to our pre-defined criteria, leaving 68 studies for full text analysis. Our analysis revealed that: (1) Most studies consider vulnerability or resilience to be generic properties of social systems; (2) Few papers measured vulnerability or resilience in a way that tests whether they are relatively stable or dynamic features of social systems; (3) Many applications rely on stock applications of existing frameworks, with little adaptation to specific cultural, societal or economic contexts; (4) There is a lack of systematic validation; (5) More hypothesis-driven studies (as opposed to descriptive mapping exercises) are required in order to develop a better understanding of the mechanisms through which vulnerability and resilience shape the capacity to prepare for, respond and recover from disasters.


* Corresponding author at: School of Architecture, Hunan University, Changsha, Hunan Province 410000, China.
*E-mail address:* Jing_Ran@foxmail.com (J. Ran).

https://doi.org/10.1016/j.scitotenv.2019.134486
0048-9697/© 2019 The Authors. Published by Elsevier B.V.

**Contents**



## 1. Introduction

Geophysical hazards pose significant threats to health, wellbeing, infrastructure and ecosystems across the globe, although there are marked geographical variations in the impacts that they give rise to. Developing nations bear a disproportionate burden of these harms, which is not a function of differential exposure per se, but rather due to limitations in governance, infrastructure, and scientific and technical capacities, as well as high levels of poverty (Pelling, 2003). Moreover, recent years have brought an emerging consensus that hazardous events and disasters are not merely intermittent shocks that leave transient (albeit often substantial) signatures, but rather are events that pose long-lasting challenges to development and poverty alleviation (UNISDR, 2015). Social vulnerability and community resilience[1] have emerged as core concepts for describing the capacity of social systems to prepare, absorb, and adapt to the risks posed by environmental shocks and natural disasters (Adger et al., 2003, Cutter et al., 2008, Klinenberg, 2015, Andrade and Szlafsztein, 2018, Hagenlocher et al., 2018). The growing prominence of these concepts is partly a response to the perceived limitations of historic approaches to disaster risk management, which focussed on technological fixes such as levees, early warning systems, and earthquake-resistant structures (Aldrich, 2012). In particular, analyses of disasters ranging from the 1995 Chicago heat wave (Klinenberg, 2015) to the Japanese tsunami of 2011 (Aldrich and Sawada, 2015) revealed that the quality of an area's "social infrastructure" may be as important as the state of its physical infrastructure in shaping impacts and recovery trajectories.

In this paper we focus on two core concepts related to social infrastructure: social vulnerability and resilience to geophysical hazards, and on their quantitative measurement within developing nations. These concepts have been studied for more than thirty years. Timmerman (1981) defined vulnerability as the degree to which a social system is adversely impacted by the occurrence of a hazardous event. The nature and extent of the adverse reaction are conditioned by the system's capacity to absorb and recover from the event. From these origins, the field has been marked by important theoretical debates on, for example, how social vulnerability relates to resilience (Bakkensen et al., 2016, Miller et al., 2010), the underlying causal processes through which social vulnerability and hazard exposure interact to generate harm (Birkmann and Van Ginkel, 2006), and even on the definitions of key concepts (Birkmann et al., 2013, Cutter et al., 2003). Moreover, whilst there is broad agreement on the core dimensions that shape social vulnerability (e.g. population growth, income, family structure, etc.) and resilience, the practice of measurement varies significantly (Rufat et al., 2015). Scholars diverge on: whether social vulnerability and resilience are generic properties of systems or are hazard specific; on what indicators best reflect the core dimensions of these constructs; on how those dimensions should be weighted (if at all); and on the preferred analytical techniques for generating composite indexes.

Another core concern is that the majority of frameworks for characterising social vulnerability and resilience have their origins in research in Western, industrialised, high-income nations, and it is questionable whether they can be readily applied to countries across the "Global South." This is because the processes generating vulnerability or resilience may differ by culture, geography or context, as may the appropriate procedures for measuring them, implying a need for culturally-tailored approaches to framework development and application. This is a critical question at this moment, given that recent years have seen a rapid growth in applications of the social vulnerability and resilience concepts across Asia and within China in particular (Fang et al., 2016, Huang et al., 2015, Zhou et al., 2014a). The purposes of such measurement exercises are various (Singh et al., 2017). For example, measurement exercises can inform prioritisation of capacity building exercises, or can shed light on the underlying mechanisms that put individuals and communities at-risk, can reveal how "vulnerability traps" emerge, or may simply be descriptive mapping exercises.

In summary, the rapidly growing literature that attempts to measure social vulnerability or resilience to geophysical hazards within developing nations is of critical importance, but has yet to

[1] We use the term community resilience to emphasise our concern with social systems, as opposed, say, to the resilience of critical infrastructure, or ecological systems. Throughout the paper, when we say resilience, it should be understood as referring to a social system (e.g. community).

be systematically synthesised. To address this deficiency, we conducted a systematic review of applications of social vulnerability and resilience frameworks in Lower and Middle Income Countries (LMICs; although we use developing nations, and the Global South as synonyms) using the PRISMA methodology (Liberati et al., 2009). We focussed on LMICs for the reasons outlined above, in addition to our belief the application of such measurement frameworks to industrialised, wealthy countries is a long-standing, well-established field, with little need for a new review. We addressed the following research questions:

- what were the underlying theoretical concepts and frameworks;
- were the frameworks intended to be generic or hazard-specific;
- what spatio-temporal scales, data sources, and analytical methods were adopted;
- what process (if any) was used for adapting the frameworks to the specific application contexts; and
- were the applications descriptive or hypothesis-driven?

## 2. Research methods

To critically appraise and synthesise the measurement of social vulnerability and resilience in LMICs, we applied the systematic review method (Liberati et al., 2009). This differs from the traditional literature review as it applies standardised and replicable methods for data collection and analysis (Petticrew, 2006). In the data collection stage, it extracts items such as peer-reviewed articles, books, papers, and reports using the same search keywords before screening them with the same criteria. In the analysis stage, each item is analysed with the same pre-defined protocol and then synthesised. The approach has its origins in medical and public health research, although it has found increasing application in fields such as ecology (Plummer et al., 2012) and risk research (Thompson et al., 2017) where concerns about objectivity and rigour are similarly paramount.

### 2.1. Data collection

We applied the PRISMA method for data collection (Liberati et al., 2009). In this method, data collection includes the steps of identification (searching and collecting data), screening, and eligibility checking. We used a combination of keywords to identify quantitative empirical studies that measured social vulnerability or resilience to geophysical hazards within low and middle income countries, using the OECD list of Official Development Assistant (ODA) recipients, 2007[2]. We searched for articles published in English between January 1980 and January 2017 using 15 databases (SCOPUS, Web of Science, ScienceDirect, ProQuest, IBSS, ASSIA, Social Service Abstract, EBSCOhost, OpenGrey SIGLE, Pubmed, EMBASE, PsycINFO, Medline, CINAHL and Google Scholar). We used the keywords "social vulnerability" or "resilience" combined with "natural hazard", "natural disaster", "environmental hazard", "climate change" or "geophysical hazard"[3] to search for studies undertaken within LMICs.

The search identified 2194 articles with an additional 1000 articles identified from Google Scholar[4]. After removing duplicates, 2152 articles remained (Fig. 1). The retrieved studies were further screened manually by reading their titles and abstracts to exclude opinion or review articles, reports, books, working papers, conference papers, theses, qualitative studies, and studies not conducted within LMICs. In addition, the following exclusion criteria were applied:

a) Exclude papers that sought to measure *perceived* (rather than objective) vulnerability;
b) Exclude papers focussed on risk assessment (unless social vulnerability or resilience were measured as sub-components);
c) Exclude papers restricted to measuring the vulnerability or resilience of sub-groups of populations, e.g., farmers, coffee growers, children, livestock breeders, etc.;
d) Exclude papers focused on capacities to adapt or respond to generalised climate change (e.g. adaptive capacity), but include papers measuring resilience or social vulnerability to climatic hazards (e.g. typhoons, wildfires, floods, etc.)

After the screening stage, 111 articles were selected for full-text assessment for eligibility (using the same criteria as above). To check the accuracy of the process, we randomly selected 10 articles (9% of the 111 papers), and a second reviewer assessed the full texts independently. Cohen's Kappa coefficient was used to measure the interrater reliability (Cohen, 1968). The higher Kappa score indicates the higher agreement between two reviewers. Usually, scores range from 0.61 to 0.8 can be seen as substantial agreement (Landis and Koch, 1977). In our study, the internal validation Kappa score was 0.78, indicating a high level of agreement on inclusion and exclusion between the reviewers.

### 2.2. Analysis framework

68 articles remained after full-text assessment. These articles were analysed with a pre-defined data extraction form (Appendix A), focussed on the five key research questions outlined in section 1.

## 3. Results

Of our 68 selected articles, we noted that work on social vulnerability of geophysical hazards in developing countries has a primary focus on Asian countries, and those that are found in the upper bracket of lower-middle income countries (called upper middle-income countries by ODA) (Table 1). Only 6 articles fell in ODA's least developed countries bracket. Table 2 summarises the data extracted from each article. The following sections present our key findings in relation to the questions posed in section 1.

### 3.1. Hazard types

24 articles measured social vulnerability or resilience with respect to all-hazards, which implies that the former properties are independent of hazard type (Table 3). 19 articles measured vulnerability or resilience to a single hazard, with flooding being the most commonly studied. 25 articles considered multiple hazards. In some cases these multiple hazards were conceptually related (e.g. 9 of the multi-hazard papers studied climatic hazards), in

[2] The list of ODA countries was downloaded from the OECD website: http://www.oecd.org/dac/financing-sustainable-development/development-finance-standards/41751233.pdf.

[3] The full list of hazard-related terms was: "natural hazard*", "natural disaster*","-hazard*", "seismic hazard*", "environmental hazard*", "climate change", "earthquake*", "flood*", "drought*", "landslide*", "tsunami*", "typhoon*", "hurricane*", "volcano*", "avalanche*", "extreme temperature*", "heat wave*", "extreme weather","cold", "wildfire*", "cyclone*","storm*", and "wave surge*".

[4] The databases were searched on 6th February 2017 except for Google Scholar, which was searched on the7th February 2017.

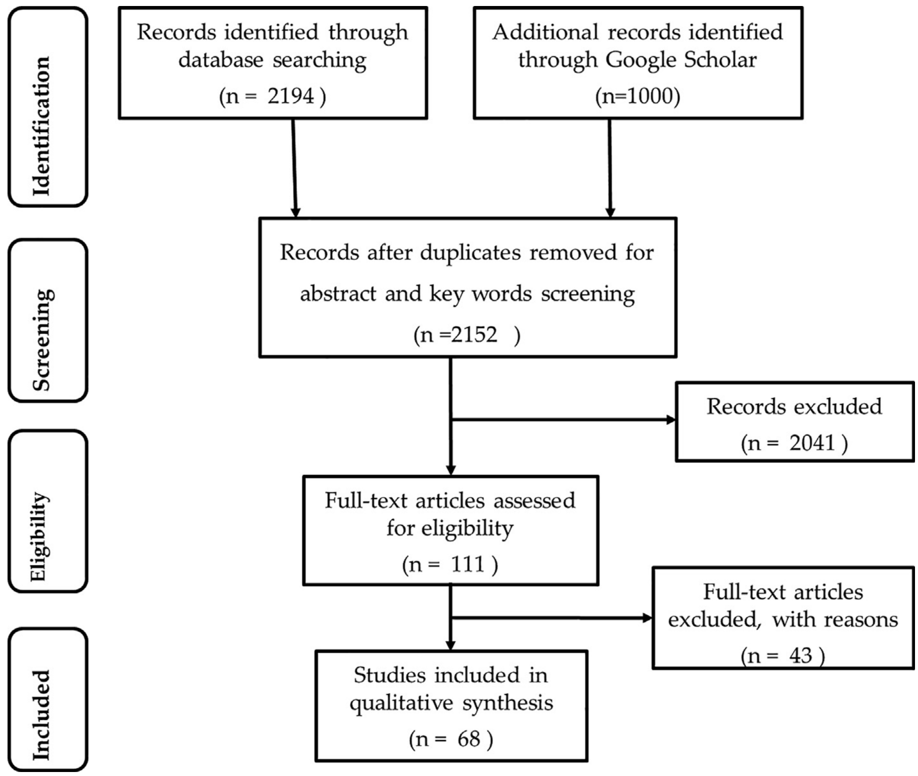



**Fig. 1.** Flow chart of the data screening process.

**Table 1**
Spatial characteristics of the selected studies.

| Continents | Number of studies | Level of development | Number of studies |
|---|---|---|---|
| Asia | 49 | Upper middle income countries | 38 |
| South America | 6 | Lower middle income countries | 18 |
| Africa | 5 | Least developed countries | 6 |
| North America | 3 | Cross national | 6 |
| Europe | 1 | | |
| Australia/Oceania | 1 | | |
| Cross continental | 3 | | |
| Total | 68 | | |

other cases the authors focussed on the set of hazards that frequently occurred within their study areas.

*3.2. The conceptualisation of social vulnerability and resilience*

Conceptualisation is the first step in any measurement exercise. At present, there is no universally agreed definition of resilience or social vulnerability (Roncancio and Nardocci, 2016). Conceptualisation can be thought of as involving two broad processes: (1) defining a broad idea of the object of study and searching for terms to describe it; (2) identifying the dimensions of the concept and their relationships. Below we present our findings in relation to these processes.

*3.2.1. Definitions*

The 68 papers drew on three primary concepts: social vulnerability (46), resilience (15), and risk (7) (of which social vulnerability was a component). Amongst the social vulnerability papers, the majority (24) considered vulnerability to extend beyond sensitivity to hazardous events and include recovery and adaptation processes (coded as V1 in Table 2 and Table 4). A smaller number (13) focussed on susceptibility, and did not consider recovery or adaptation (coded as V2). For instance, in the study of Huang et al. (2013), vulnerability is defined as "the characteristic of a place to be wounded and has little capacity to cope [...] without the consideration of resilience (the ability to recover rapidly from disaster)". 7 social vulnerability papers lacked a clear definition of their central concept. On the other hand, when social vulnerability was conceived of within the broader conceptual framework of risk (7 articles), it was typically more narrowly defined to exclude recovery and adaptation.

The resilience articles (15) defined their primary concept with varying terminology, but broadly sharing the idea that resilience is the ability of a system, community or person to prepare, cope with, recover and adapt to a hazard or hazardous event. However, these articles had varying views of how resilience related to social vulnerability. 8 of these papers conceived of vulnerability as the inverse of resilience (coded as R1); 3 papers conceived of vulnerability as a subset of resilience (with the former not considering recovery / adaptation processes) (coded as R2); 2 papers conceived of vulnerability and resilience as overlapping concepts but with independent features (coded as R3); whilst 2 papers did not explicitly define vulnerability, leaving the relationship between the two concepts unclear (coded as R4).

**Table 2**
Data extracted.

| (Author, Year) | Study Area | Core concept | Definition | Hazard types | Geographic unit | Data source | Operationalisation approach | Analytical approach | Is validation method applied? | Is hypothesis tested? |
|---|---|---|---|---|---|---|---|---|---|---|
| (Ahsan and Warner, 2014) | Bangladesh | Socio-economic vulnerability | V1 | Climatic hazards | Neighbourhood | Mixture | Theory-driven | Scoring – Additive model | No | No |
| (Akter and Mallick, 2013) | Bangladesh | Socio-economic resilience | R3 | Storms and storm flooding | Household | Survey | Theory-driven | Regression | No | Yes |
| (Ancog et al., 2016) | Philippines | Vulnerability | V1 | Flooding | Neighbourhood | Survey | Mixture | Scoring –PCA/ Factor analysis | Yes | No |
| (Antwi-Agyei et al., 2013) | Ghana | Livelihood vulnerability | LV | Climatic hazards | Neighbourhood | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Asadzadeh et al., 2015) | Iran | Resilience | R1 | Earthquake | District | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Balica et al., 2009) | Multiple | Vulnerability | V1 | Flooding | Catchment | No info | Mixture | Scoring – Multiplicative model | No | No |
| (Bene et al., 2016) | Multiple | Resilience | R1 | Generic | Household | Survey | Theory-driven | Regression | No | Yes |
| (Boruff and Cutter, 2007) | Multiple - Saint Vincent and Barbados | Vulnerability | V3 | Flood, fire, landslides, storm surge, tsunami, volcanic eruption | District | Census | Data-driven | Scoring– PCA/ Factor analysis | Yes | No |
| (Brink and Davidson, 2015) | Indonesia | -Resilience | R1 | Earthquake | Local government/town | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Busby et al., 2014) | Multiple - Africa | Vulnerability | V2 | Climatic hazards | Grid | Census | Mixture | Scoring – Additive model | No | No |
| (Chakraborty and Joshi, 2016) | India | Vulnerability | V1 | Cyclones, floods, droughts, earthquakes, sea-level rise | District | Census | Data-driven | Scoring – Additive model | No | No |
| (Chen et al., 2013) | China | Social vulnerability | V1 | Generic | District | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (de Loyola Hummell et al., 2016) | Brazil | Social vulnerability | V3 | Generic | Cities | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Ding et al., 2016) | China | Vulnerability | V2 | Debris flow | Grids | Other - Remote sensing | Data-driven | Scoring – Additive model | No | No |
| (Ebert et al., 2009) | Honduras | Risk - Social vulnerability | Risk1 | Generic | Neighbourhood | Other - Remote sensing | Theory-driven | Regression | Yes | Yes |
| (Gawith et al., 2016) | Fiji | Resilience | R1 | Climatic hazards | Neighbourhood | Survey | Theory-driven | Regression | No | Yes |
| (Ge et al., 2013) | China | Social vulnerability | V1 | Generic | Local government/town | Census | Data-driven | Scoring – PCA/ Factor analysis | Yes | No |
| (Gil-Guirado et al., 2016) | Multiple - Spain and Argentina | Vulnerability | V1 | Floods and droughts | Cities | Other - Documents and newspapers | Theory-driven | Scoring – Additive model | No | No |
| (Hou et al., 2016) | China | Social vulnerability | V3 | Landslides, collapse and debris flows | Province | Census | Theory-driven | Scoring – Data Envelop Analysis | No | Yes |
| (Huang et al., 2013) | China | Vulnerability | V2 | Generic | Province | Census | Data-driven | Scoring – Data Envelop Analysis | No | No |
| (Huang et al., 2015) | China | Social vulnerability | V2 | Generic | Local government/town | No info | Data-driven | Scoring – PCA/ Factor analysis | No | No |
| (Ignacio et al., 2015) | Philippines | Social vulnerability | V3 | Storms and storm flooding | District | Census | Data-driven | Scoring – Additive model; Regression | No | Yes |
| (Inostroza et al., 2016) | Chile | Vulnerability | V1 | Heat wave | District | Census | Mixture | Scoring – Additive; Cluster analysis | No | No |
| (Kafle, 2012) | Indonesia | Resilience | R2 | Cyclones, floods, droughts, | Neighbourhood | Survey | Theory-driven | Scoring – Additive | No | No |

(continued on next page)

**Table 2** (*continued*)

| (Author, Year) | Study Area | Core concept | Definition | Hazard types | Geographic unit | Data source | Operationalisation approach | Analytical approach | Is validation method applied? | Is hypothesis tested? |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | earthquakes, sea-level rise | | | | model | | |
| (Kotzee and Reyers, 2016) | South Africa | Resilience | R2 | Flooding | District | Census | Data-driven | Scoring – PCA/ Factor analysis | No | No |
| (Kovacevic-Majkic et al., 2014) | Serbia | Risk - Vulnerability | Risk1 | Generic | Local government/town | Census | Data-driven | Scoring – Additive model | No | No |
| (Künzler et al., 2012) | Colombia | Risk - Vulnerability | Risk1 | Flooding | District | Census | Theory-driven | Scoring – Additive model | No | No |
| (Kusumastuti et al., 2014) | Indonesia | Resilience | R2 | Generic | Cities | Mixture | Theory-driven | Scoring – Additive model | No | No |
| (Lam et al., 2014) | Multiple - Caribbean region | Vulnerability and adaptive capacity | V1 | Storms and storm flooding | Nation | Census | Theory-driven | Scoring – Additive model; Regression | Yes | Yes |
| (Lawal and Arokoyu, 2015) | Nigeria | Risk - Social vulnerability | Risk1 | Generic | Local government/town | Census | Theory-driven | Scoring – Additive model | No | No |
| (Lee, 2014) | Taiwan | Social vulnerability | V1 | Climatic hazards | Cities | Census | Mixture | Scoring – Additive model | No | No |
| (Li et al., 2016) | China | Resilience | R1 | Earthquake | Local government/town | Census | Data-driven | Scoring –PCA; Regression | No | Yes |
| (Lin and Polsky, 2016) | Taiwan | Livelihood vulnerability | LV | Storms and storm flooding | Neighbourhood | Mixture | Theory-driven | Scoring – Additive model | No | No |
| (Liu and Li, 2016) | China | Social vulnerability | V3 | Flooding | Households | Survey | Data-driven | Scoring – PCA/ Factor analysis | No | No |
| (Lixin et al., 2014) | China | Social vulnerability | V2 | Generic | Cities | Census | Theory-driven | Scoring – Additive model | No | No |
| (Maharani et al., 2016) | Indonesia | Social vulnerability | V1 | Volcanic hazard | District | Census | Theory-driven | Classification | No | No |
| (Miao and Ding, 2015) | China | Social vulnerability | V2 | Landslides, collapse and debris flows | Local government/town | Census | Mixture | Scoring – Additive model | No | No |
| (Muller et al., 2011) | Chile | Risk - Vulnerability | Risk1 | Flooding | Neighbourhood | Mixture | Theory-driven | Scoring – Additive model | No | No |
| (Mustafa et al., 2011) | India | Vulnerability | V1 | Generic | Household | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Mwale et al., 2015) | Malawi | Risk - Vulnerability | Risk2 | Flooding | Neighbourhood | Mixture | Theory-driven | Scoring – Additive model | No | No |
| (Ni et al., 2015) | China | Resilience | R4 | Earthquake | Household | Survey | Theory-driven | Scoring – Additive model; Regression | No | No |
| (Orencio and Fujii, 2013) | Philippines | Community vulnerability | V2 | Generic | Neighbourhood | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Pati et al., 2014) | Philippines | Vulnerability | V3 | Flooding | District | Census | Theory-driven | Scoring – Additive model | No | No |
| (Piya et al., 2016) | Nepal | Vulnerability | V1 | Climatic hazards | Households | Survey | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Qasim et al., 2016) | Pakistan | Resilience | R1 | Flooding | District | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Rahman et al., 2015) | Bangladesh | Vulnerability | V3 | Earthquake and fire | Buildings | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Razafindrabe et al., 2009) | Multiple - Asia cities | Resilience | R1 | Climatic hazards | Cities | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Rogelis et al., 2016) | Colombia | Vulnerability) | V2 | Floods and debris flow | Grids | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Roncancio and Nardocci, | Brazil | Social vulnerability | V1 | Generic | Catchment | Census | Data-driven | Scoring – PCA; Cluster analysis | No | No |

**Table 2** (*continued*)

| (Author, Year) | Study Area | Core concept | Definition | Hazard types | Geographic unit | Data source | Operationalisation approach | Analytical approach | Is validation method applied? | Is hypothesis tested? |
|---|---|---|---|---|---|---|---|---|---|---|
| 2016) | | | | | | | | | | |
| (Rubin, 2014) | Vietnam | Vulnerability | V1 | Climatic hazards | Province | Census | Data-driven | Regression | No | No |
| (Sherly et al., 2015) | India | Vulnerability | V1 | Generic | District | Census | Mixture | Scoring – Data Envelop Analysis | No | No |
| (Siagian et al., 2014) | Indonesia | Social vulnerability | V1 | Generic | District | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Siebeneck et al., 2015) | Tailand | Resilience | R4 | Generic | Province | Census | Mixture | Scoring – PCA/ Factor analysis | No | No |
| (Su et al., 2015) | China | Social vulnerability | V1 | Climatic hazards | Cities | Census | Data-driven | Scoring – PCA; Cluster analysis | Yes | No |
| (Sudmeier et al., 2013) | Nepal | Resilience | R1 | landslide and flooding | Neighbourhood | Survey | Theory-driven | Scoring – Additive model | No | No |
| (Yan and Li, 2016) | China | Social vulnerability | V2 | Generic | Province | Census | Mixture | Scoring – Factor analysis; Cluster analysis | No | No |
| (Yan and Xu, 2010) | China | Vulnerability | V2 | Soil erosion, river pollution, stream flow, sandification, debris flows, mining | Grid | Census | Theory-driven | Scoring - Multiplicative model | No | No |
| (Yang et al., 2015) | China | Social vulnerability | V1 | Generic | Province | Census | Data-driven | Scoring – Factor analysis; Cluster analysis | No | No |
| (Yenneti et al., 2016) | India | Social vulnerability | V1 | Generic | Province | Census | Theory-driven | Scoring – Additive model | No | No |
| (Zebardast, 2013) | Iran | Social vulnerability | V1 | Earthquake | Local government/town | Census | Data-driven | Scoring – Additive model | Yes | No |
| (Zeng et al., 2012) | China | Social vulnerability | V2 | Generic | Grids | Other - Remote sensing | Theory-driven | Scoring – Additive model | No | No |
| (Zhang and Huang, 2013) | China | Social vulnerability | V2 | Generic | District | Census | Theory-driven | Scoring – Additive model | No | No |
| (Zhang and You, 2014) | China | Social vulnerability | V1 | Flooding | Cities | Census | Data-driven | Scoring – PCA/ Factor analysis | No | No |
| (Zhou et al., 2010) | China | Resilience | R3 | Droughts | Local government/town | Mixture | Theory-driven | Scoring each index | No | No |
| (Zhou et al., 2014a) | China | Social vulnerability | V1 | Generic | Province | Census | Mixture | Scoring – PCA/ Factor analysis | Yes | Yes |
| (Zhou et al., 2014b) | China | Social vulnerability | V1 | Generic | Local government/town | Census | Mixture | Scoring –PCA/ Factor analysis | No | No |
| (Zhou et al., 2015) | China | Risk - Vulnerability | Risk2 | Earthquakes, droughts, floods, low temperatures, snow and gale | Province | Census | Theory-driven | Scoring – Additive model | No | No |
| (Zou, 2012) | China | Vulnerability | V2 | Earthquake and floods | Province | Census | Theory-driven | Correlation test – Structural Equation Model | No | Yes |

**Table 3**
Hazard types studied by the selected papers.

| | Hazard-specific or generic | Number of studies | Articles |
|---|---|---|---|
| Generic (24) | Generic | 24 | Bene et al. (2016), Chen et al. (2013), de Loyola Hummell et al. (2016), Ebert et al. (2009), Ge et al. (2013), Huang et al. (2013), Huang et al. (2015), Kovacevic-Majkic et al. (2014), Kusumastuti et al. (2014), Lawal and Arokoyu (2015), Lixin et al. (2014), Mustafa et al. (2011), Orencio and Fujii (2013), Roncancio and Nardocci (2016), Sherly et al. (2015), Siagian et al. (2014), Siebeneck et al. (2015), Yan and Li (2016), Yang et al. (2015), Yenneti et al. (2016), Zeng et al. (2012), Zhang and Huang (2013), Zhou et al. (2014a), Zhou et al. (2014b) |
| One specific type of hazards (19) | Flooding | 10 | Ancog et al. (2016), Balica et al. (2009), Kotzee and Reyers (2016), Künzler et al. (2012), Liu and Li (2016), Muller et al. (2011), Mwale et al. (2015), Pati et al. (2014), Qasim et al. (2016), Zhang and You (2014) |
| | Earthquake | 5 | Asadzadeh et al. (2015), Brink and Davidson (2015), Li et al. (2016), Ni et al. (2015), Zebardast (2013) |
| | Debris flow | 1 | Ding et al. (2016) |
| | Volcanic hazard | 1 | Maharani et al. (2016) |
| | Heat wave | 1 | Inostroza et al. (2016) |
| | Droughts | 1 | Zhou et al. (2010) |
| Multi-hazards (25) | Climatic hazards | 9 | Ahsan and Warner (2014), Antwi-Agyei et al. (2013), Busby et al. (2014), Gawith et al. (2016), Lee (2014), Piya et al. (2016), Razafindrabe et al. (2009), Rubin (2014), Su et al. (2015) |
| | Flood, fire, landslides, storm surge, tsunami, volcanic eruption | 1 | Boruff and Cutter (2007) |
| | Cyclones, floods, droughts, earthquakes, sea-level rise | 2 | Chakraborty and Joshi (2016), Kafle (2012) |
| | Soil erosion, river pollution, stream flow, sandification, debris flows, mining | 1 | Yan and Xu (2010) |
| | Earthquakes, droughts, floods, low temperatures, snow and gale | 1 | Zhou et al. (2015) |
| | Storms and storm flooding | 4 | Akter and Mallick (2013), Ignacio et al. (2015), Lam et al. (2014), Lin and Polsky (2016), |
| | Landslides, collapse and debris flows | 2 | Hou et al. (2016), Miao and Ding (2015) |
| | Earthquake and fire | 1 | Rahman et al. (2015) |
| | Earthquake and floods | 1 | Zou (2012) |
| | Floods and debris flow | 1 | Rogelis et al. (2016) |
| | Landslide and flooding | 1 | Sudmeier et al. (2013) |
| | Floods and droughts | 1 | Gil-Guirado et al. (2016) |

**Table 4**
Definitions of the concepts.

| Key concepts | Definitions | | Articles |
|---|---|---|---|
| Vulnerability 46 | V1:Vulnerability includes recovery and adaptation capacity 24 | | Ahsan and Warner (2014) Ancog et al. (2016), Balica et al. (2009), Chakraborty and Joshi (2016), Chen et al. (2013), Ge et al. (2013), Gil-Guirado et al. (2016), Inostroza et al. (2016), Lam et al. (2014), Lee (2014), Maharani et al. (2016), Mustafa et al. (2011), Piya et al. (2016), Roncancio and Nardocci (2016), Rubin (2014), Sherly et al. (2015), Siagian et al. (2014), Su et al. (2015), Yang et al. (2015), Yenneti et al. (2016), Zebardast (2013), Zhang and You (2014), Zhou et al. (2014a), Zhou et al. (2014b) |
| | V2: Vulnerability is being susceptible to hazards 13 | | Busby et al. (2014), Ding et al. (2016), Huang et al. (2013), Huang et al. (2015), Lixin et al. (2014), Miao and Ding (2015), Orencio and Fujii (2013), Rogelis et al. (2016), Yan and Li (2016), Yan and Xu (2010), Zeng et al. (2012), Zhang and Huang (2013), Zou (2012) |
| | V3: No clear definition of vulnerability 7 | | Boruff and Cutter (2007), de Loyola Hummell et al. (2016), Hou et al. (2016), Ignacio et al. (2015), Liu and Li (2016), Pati et al. (2014), Rahman et al. (2015) |
| | LV: Livelihood Vulnerability 2 | | Antwi-Agyei et al. (2013), Lin and Polsky (2016) |
| Resilience 15 | Ability to resist, absorb and accommodate and recover 15 | R1: Resilience as the inverse of vulnerability 8 | Asadzadeh et al. (2015), Bene et al. (2016), Brink and Davidson (2015), Gawith et al. (2016), Li et al. (2016), Qasim et al. (2016), Razafindrabe et al. (2009), Sudmeier et al. (2013) |
| | | R2: Vulnerability is a subset of resilience 3 | Kafle (2012), Kotzee and Reyers (2016), Kusumastuti et al. (2014) |
| | | R3: Vulnerability and resilience are independent concepts but have overlaps with each other 2 | Akter and Mallick (2013), Zhou et al. (2010) |
| | | R4: Defined Resilience but not vulnerability 2 | Ni et al. (2015), Siebeneck et al. (2015) |
| Risk 7 | Risk1: Vulnerability is being susceptible to hazard 5 | | Ebert et al. (2009), Kovacevic-Majkic et al. (2014), Künzler et al. (2012), Lawal and Arokoyu (2015), Muller et al. (2011) |
| | Risk2: Vulnerability includes susceptibility, and capacity to adapt/recover 2 | | Mwale et al. (2015), Zhou et al. (2015) |

**Table 5**
Number of articles that for each hazard type and concepts.

| Hazard types | Defined under the concept of risk | Resilience | Vulnerability |
|---|---|---|---|
| Generic | 3 | 3 | 19 |
| One hazard | 3 | 8 | 13 |
| Multi-hazard | 1 | 3 | 15 |

An interesting pattern is that the social vulnerability papers tended to (implicitly) assume that it was a property independent of hazard types, whilst the resilience articles tended to focus on single hazards or hazard classes (Table 5).

*3.2.2. Conceptual framework*

The most frequently adopted conceptual framework was Cutter et al.'s (2003) Social Vulnerability Index (SoVI) (referred to by 17 out of 68 studies). Cutter et al.'s (2008) Disaster Resilience of Place model (DROP) was the second most prominently referenced conceptual framework (5 papers). Aside from these two frameworks, a somewhat miscellaneous group of frameworks or theories are referenced as being the authors' point of departure in constructing their frameworks. However, several papers (26) did not explicitly elaborate their conceptual framework, in terms of clearly defining their overarching concept, setting out the underlying dimensions (of social vulnerability or resilience), and explaining how those dimensions (interact to) generate vulnerability or resilience (e.g. some articles simply refer to Cutter et al.'s SoVI model as their inspiration, without explaining its key assumptions and components). We consider these articles to lack a clear conceptual framework.

*3.3. Measuring social vulnerability and resilience: Data and methods*

*3.3.1. Geographic unit, data source, and temporal assessment*

14 of our selected papers analysed social vulnerability or resilience at the district scale, which is typically the smallest unit in publicly available census data. 23 studies had higher spatial resolutions, such as neighbourhoods, 1 km$^2$ pixel grids, or households (Table 6). The remaining 31 papers adopted relatively coarse spatial resolutions, ranging from the town to the nation (including catchments). Table 6 sets out the relationship between unit of analysis and the sources of data in our selected papers. Only 8 articles measured social vulnerability or resilience over multiple years; all of these articles relied upon census data.

Note: Articles in red with underline marked the studies conducted measurement for multiple years.

*3.3.2. The methods to assess social vulnerability and resilience*

We generalised three approaches to operationalise the conceptual frameworks (social vulnerability or resilience) within our selected papers: theory-driven, data-driven, and mixed approaches (Table 7). Theory-driven approaches use their conceptual framework to guide the selection of indicators (which may necessitate generating novel data e.g. by survey), whilst data-driven approaches generate a list of indicators from available datasets (e.g. census) and screen them for relevance before merging them into factors or components. Among the 42 articles with a clear conceptual framework, the majority (25) applied a theory-driven approach, whilst 11 adopted a mixed approach, and 6 articles were data-driven (which leads to questions about the role of the conceptual framework in the latter articles). Of the 26 articles without a clear conceptual framework, the largest portion was data-driven (11), with 6 adopting a mixed approach, and only 9 articles being theory-driven. It may seem puzzling that any articles lacking a clear conceptual framework could adopt a theory-driven approach. These articles typically justified their indicator selection with reference to standard practices or conventions.

After selecting indicators, the majority of the articles (64) created composite indexes of vulnerability or resilience ("scoring"), using methods such as sum, average, multiply, factor analysis or data envelop analysis (Table 8). In addition, 5 articles conducted a cluster analysis based on scoring. Besides the papers listed in Table 8, 5 articles applied regression without applying any scoring techniques, 1 applied classification, and 2 other articles did not create composite indexes of social vulnerability or resilience.

*3.3.3. Validation*

Only 8 papers claimed to have validated their frameworks or results. Three general validation approaches were applied. The first validation method compares the results from different approaches to generating composite indexes. For example, Zebardast (2013) conducted a correlation test between the results from their measurement exercise with the results generated by Factor Analysis and Analytical Network Process. The second approach compares estimates of social vulnerability or resilience generated by the authors' frameworks with estimates of those concepts from independent sources. For instance, Boruff and Cutter (2007) sought to validate their measurement of social vulnerability by comparing their results with expert judgments of vulnerability. Using objective measures that are thought to correlate with levels of resilience or social vulnerability following a hazardous event - such as mortality, morbidity, and rebuilding timescales – is the third approach to validation. Four articles in our selected papers used this approach, 3 of which relied upon some measure of economic loss as the validation variable (Ge et al., 2013, Su et al., 2015, Zhou et al., 2014a), whilst one used storm damages (Lam et al., 2014).

*3.4. Adaptation to local context*

The majority of resilience and social vulnerability and resilience frameworks applied within our selected papers were originally developed in wealthy, industrialised, Western nations. 37 studies (of 68) made an explicit attempt at adaptation to the particular geographic, social or cultural contexts of their study regions. We classify three forms of adaptation: adapting the standard measurement frameworks (i.e. identifying new dimensions, or removing inappropriate ones); adapting the variables selected to represent dimensions within those frameworks; and weighting the dimensions of those frameworks. We discuss these in turn.

Efforts to adapt standard conceptual frameworks were typically modest amendments to SoVI or DROP, or simply ways of implementing those frameworks that were sensitive to particular local contexts. However, the methodology for doing so was typically not made explicit. For example, Roncancio and Nardocci (2016) modified SoVI by adding nine variables relating to sanitation facilities, on the grounds that these are particularly important drivers of social vulnerability in Sao Paulo. Similarly, Gawith et al. (2016) implemented a pared down version of the DROP framework, focussing on variables representing social cohesion, cooperation, social organisation, dynamism and institutional support, on the logic that these constructs are critical drivers of vulnerability in the Fijian context.

6 papers drew on interviews or focus groups involving local communities or elites to screen and select indicators and data sources. For example, working in the Thai context, Siebeneck et al. (2015) drew upon qualitative interviews to identify bespoke indicators for institutional capacity, including the number of Rotary Clubs and the number of monks and novices.

**Table 6**
Number of articles that applied each geographic unit and data source.

| Geographic unit | Notes | Survey 16 | Census (including census and census data in the GIS format) 39 | Mixture of survey, census, and GIS data 7 | Other (remote sensing data and documents) 4 | No information 2 |
|---|---|---|---|---|---|---|
| Nation 1 | | | 1 Lam et al. (2014) | | | |
| Province 10 | | | 9 Huang et al. (2013) , (Hou et al., 2016), Rubin (2014), Siebeneck et al. (2015), Yan and Li (2016), Yang et al. (2015), Yenneti et al. (2016), Zhou et al. (2015), Zou (2012) | 1 Zhou et al. (2014a) | | |
| City 8 | | 1 Razafindrabe et al. (2009) | 5 de Loyola Hummell et al. (2016), Lee (2014), Lixin et al. (2014), Su et al. (2015), Zhang and You (2014) | 1 Kusumastuti et al. (2014) | 1 Gil-Guirado et al. (2016) | |
| Local government or town 10 | Also includes other administrative units such as local government, town, and municipalities | 1 Brink and Davidson (2015) | 7 Ge et al. (2013), Kovacevic-Majkic et al. (2014), Lawal and Arokoyu (2015), Li et al. (2016), Miao and Ding (2015), Zebardast (2013), Zhou et al. (2014b) | 1 Zhou et al. (2010) | | 1 Huang et al. (2015) |
| District 14 | Typically the smallest statistical unit available in census data, including districts, villages, barangays, and wards | 1 Qasim et al. (2016) | 13 Asadzadeh et al. (2015), Boruff and Cutter (2007), Chakraborty and Joshi (2016), Chen et al. (2013), Ignacio et al. (2015), Inostroza et al. (2016), Kotzee and Reyers (2016), Künzler et al. (2012), Maharani et al. (2016), Pati et al. (2014), Sherly et al. (2015), Siagian et al. (2014), Zhang and Huang (2013) | | | |
| Neighbour-hood 11 | Also includes community | 6 Ancog et al. (2016), Antwi-Agyei et al. (2013), Gawith et al. (2016), Kafle (2012), Orencio and Fujii (2013), Sudmeier et al. (2013) | | 4 Ahsan and Warner (2014), Lin and Polsky (2016), Muller et al. (2011), Mwale et al. (2015) | 1 Ebert et al. (2009) | |
| Grid 7 | Pixels as unit, such as 1 km*1km grid | 7 Akter and Mallick (2013), Bene et al. (2016), Liu and Li (2016), Mustafa et al. (2011), Ni et al. (2015), Piya et al. (2016), Rahman et al. (2015) | | | | |
| Catchment 2 | A hazard catchment; varies in scale | | 1 Roncancio and Nardocci (2016) – small sub-catchments in one city | | | 1 Balica et al. (2009) – large river basins that cover cities and provinces |
| Household / individuals 5 | | | 3 Busby et al. (2014), Rogelis et al. (2016), Yan and Xu (2010) | | 2 Ding et al. (2016), Zeng et al. (2012) | |

Assigning different weights to indicators is another form of contextual adaptation, which 20 articles adopted. Of these, 15 articles consulted with local experts and residents to decide context-dependent weights, whilst 5 studies appealed rather informally to the authors' experience or previous studies as the grounds for assigning weights.

### 3.5. Hypothesis testing

Although the focus of our paper is on the application of frameworks for measuring social vulnerability and resilience, we also considered what research questions, if any, the measurement frameworks were applied to answer. Only 6 of our selected arti-

**Table 7**
Operationalisation approach applied by selected articles.

| Operationalisation approach | Framework | |
|---|---|---|
| | With framework (42 articles) | Without clear framework (26 articles) |
| Theory driven | 25 | 9 |
| Data driven | 6 | 11 |
| Mixture of theory- and data-driven | 11 | 6 |

**Table 8**
Analysis methods applied to create composite indexes of vulnerability.

| Analytical techniques | Number of articles | Articles |
|---|---|---|
| Sum/average (additive model) | 34 | Ahsan and Warner (2014), Antwi-Agyei et al. (2013), Brink and Davidson (2015), Busby et al. (2014), Chakraborty and Joshi (2016), Ding et al. (2016), Gil-Guirado et al. (2016), Kafle (2012), Kovacevic-Majkic et al. (2014), Künzler et al. (2012), Kusumastuti et al. (2014), Lawal and Arokoyu (2015), Lee (2014), Lin and Polsky (2016), Lixin et al. (2014), Miao and Ding (2015), Muller et al. (2011), Mustafa et al. (2011), Mwale et al. (2015), Orencio and Fujii (2013), Pati et al. (2014), Qasim et al. (2016), Rahman et al. (2015), Razafindrabe et al. (2009), Sudmeier et al. (2013), Yenneti et al. (2016), Zebardast (2013), Zeng et al. (2012), Zhang and Huang (2013), Zhou et al. (2015), Ignacio et al. (2015)[a], Inostroza et al. (2016)[b], Lam et al. (2014)[a], Ni et al. (2015)[a] |
| PCA/Factor analysis | 21 | Ancog et al. (2016), Asadzadeh et al. (2015), Boruff and Cutter (2007), Chen et al. (2013), de Loyola Hummell et al. (2016), Ge et al. (2013), Huang et al. (2015), Kotzee and Reyers (2016), Liu and Li (2016), Piya et al. (2016), Rogelis et al. (2016), Siagian et al. (2014), Siebeneck et al. (2015), Yang et al. (2015) [b], Zhang and You (2014), Zhou et al. (2014a), Zhou et al. (2014b), Li et al. (2016)[a], Roncancio and Nardocci (2016)[b], Su et al. (2015)[b], Yan and Li (2016)[b] |
| Multiplicative model | 2 | Balica et al. (2009), Yan and Xu (2010) |
| Data Envelop Analysis | 3 | Hou et al. (2016), Huang et al. (2013), Sherly et al. (2015) |

Note: Articles underlined and in red font conducted measurement over multiple years.
a These papers also conducted regression analyses.
b These papers performed cluster analysis after creating composite indexes.

cles tested one or more hypothesis (Akter and Mallick, 2013; Gawith et al., 2016; Zou, 2012; Zhou et al., 2014a; Bene et al., 2016; Rubin, 2014). They posed questions such as under what conditions, and for which hazard types, does social capital contribute to resilience (Bene et al., 2016, Gawith et al., 2016)? And are relief funds allocated in ways that prioritise the most vulnerable communities (Zhou et al., 2014a)? The remainder were largely descriptive mapping exercises.

## 4. Discussion

### *4.1. Social vulnerability, resilience and hazard types*

Should vulnerability and resilience be conceived of as inherent properties of social systems, or are they better viewed as a function of specific hazards or hazard classes? There is no clear consensus on this within our selected articles. 24 papers measured social vulnerability or resilience in relation to all-hazards; 19 in relation to a single hazard; whilst 25 papers explored multiple hazards. Is the all-hazards approach defensible? Is, for example, resilience plausibly thought of as a generic stock of resources that can be activated and mobilised in the same fashion regardless of the specific hazard in question? After all, droughts, heat waves, earthquakes and so forth differ in terms of their foreseeability, available risk mitigation options, and characteristic damages. For example, agrarian communities facing persistent climatic hazards (e.g. prolonged droughts) will likely have evolved a series of practices, technologies and institutions that are tailored to those specific threats – e.g. networks for sharing knowledge and technologies on drought agricultural practices, land tenure institutions, co-operative associations to manage resource exploitation and buffer oscillations in commodity prices, and pooled informal insurance networks (MacGillivray, 2018). The converse is likely to be true for communities exposed to hazards with long historical return periods such as volcanic eruptions volcanic eruptions, earthquakes or tsunamis (England and Jackson, 2011) or where new hazards are triggered due to an unanticipated multi-hazard event. For example, in response to the 2008 Wenchuan earthquake, new debris flow hazards exposed recovering communities to a new suite of previously unknown hazards (Huang and Fan, 2013). In short, whether a society will be resilient (or vulnerable) to a given hazard or set of hazards depends to a large degree on the nature of those hazards, specifically whether there is some inherent adaptive capacity to a particular hazard (see also (Di Baldassarre et al., 2015). The majority of our selected articles measured social vulnerability or resilience in the context of a particular hazard or suite of multihazards. However, there was limited discussion within those articles as to how the specific features of the hazards under consideration had shaped the development of their frameworks.

### *4.2. Concepts, frameworks and adaptation to context*

Although there has been a dramatic increase in resilience-related research in recent years, the majority of our selected papers relied on social vulnerability as their primary concept (46), rather than resilience (15). Intriguingly, whilst the concept of resilience is often critiqued for its ambiguity, with some arguing that the resultant lack of clarity renders the concept vacuous, there was broad consistency in how it was understood and defined within our papers. Social vulnerability, in contrast, was defined in two different ways in our papers, the distinction turning on whether it was construed as extending beyond the susceptibility to hazards to encompass recovery and adaptation capacities (see section 3.2.2). This observation could be dismissed as "mere semantics," but we take the view that semantics matter, on the grounds that coherent theory-building and the accumulation of empirical findings requires some basic agreements on core concepts.

Two conceptual frameworks were widely drawn upon, both developed by Cutter and colleagues: the Disaster Resilience of Place Model (DROP), and the Social Vulnerability Index (SoVI). In SoVI, social vulnerability is seen as being comprised of a set of antecedent conditions that shape hazard susceptibility, although Cutter herself later came to view it as inadequately considering structural drivers (Cutter et al., 2008). This motivated the later development of DROP – which extends beyond susceptibility to consider adaptation and coping capacities. The two approaches also differ in that DROP is more of an overarching conceptual framework, whilst SoVI is more operational and can be implemented in relatively routine fashion.

The popularity of SoVI in particular[5], allied with the fact that it can be readily implemented in cookbook fashion, partly explains why the majority of papers relied upon stock applications of existing frameworks. Where adaptation took place it was typically relatively modest – e.g. tailoring the selection of a specific variable (e.g. proxy measures for social capital in Thailand) to better reflect particular socio-cultural contexts – and often with little discussion of the underlying method for doing so. Whether this lack of explicit, theorised attempts to tailor frameworks to particular cultural, economic and social contexts is a problem depends on whether one considers that resilience and vulnerability are composed of universal dimensions whose weights are invariant, or views them as operating through more context-dependent processes. Ultimately, this is an empirical question, yet there are strong a priori grounds to suspect that the latter is true, given that there are relatively few, if any, exact laws in the social sciences. Put in less abstract terms, we consider it implausible that the drivers of resilience and vulnerability, their relative importance, and their ideal measures, are likely to be stable across political contexts, cultural setting, scale, and geography (e.g. semi-arid region vs. glacier-dependent river basin).

A separate question is the influence of context or geography on measurement error, which is of particular relevance for those papers that relied upon survey data. Put another way, culture may condition how survey questions are interpreted and responded to. For example, De Silva et al. (2006) found that respondents in many developing countries interpreted questions relating to group membership and social support that differed systematically from those of the researchers (e.g. typically interpreting the latter in terms of economic support, rather than emotional or instrumental support). Similarly, Rubin (2015) questions whether the reported high levels of social capital in Vietnam are inflated by systematic measurement error, the idea being that responses to common survey questions intended to measure trust and reciprocity could be biased by a desire on the part of respondents to reflect the official party line (e.g. celebrating needs of society over that of the individual citizen). In the same vein, membership of organisations closely associated with the ruling party in authoritarian regimes may better reflect patronage networks, membership of which is necessary for extracting rents, rather than reflecting trust or respect (Gainsborough, 2007; Rubin, 2015). There was little evidence of considerations of these kinds of sources of measurement error – where social or cultural contexts influence how survey questions are interpreted, or shape incentives for how to respond to them – within our selected papers. Taken as a whole, the foregoing analysis suggests that the development of methodologically sound procedures for tailoring measurement frameworks for specific cultural or social contexts is an important research need.

### 4.3. Gaps in data, methods, and measurements

The reliability, relevance and completeness of data sources used in our selected papers is of particular interest. The majority of papers relied upon census data, with only 15 articles generating their own survey data. Whilst census data typically confers the benefits of standardisation, reliability and broad spatial and temporal coverage, it bears reminding that it is collected for entirely different purposes than the measurement of resilience or vulnerability. As such, there are legitimate questions as to whether the variables commonly collected will be both relevant (i.e. will the variables relate to the theoretical constructs of interest) and complete (in terms of covering all dimensions of vulnerability or resilience). This is particularly true for developing countries, where census exercises are typically resource-constrained, and missing data is often a significant problem. Another issue is that a reliance on census data places a basic constraint on spatial resolution, with district-scale typically being the smallest scale at which data is made publicly available.

Another limitation was the lack of systematic efforts at validation. 8 papers purported to attempt some form of validation, but these were either limited in scope or questionable in approach. For example, expert judgment was used to provide a "reality check" on estimates of social vulnerability. This approach is in our view simply too informal. For example, what would constitute reasonable agreement between framework estimates and expert judgments of social vulnerability in order for validation to have been achieved? And in instances where experts and framework outputs are viewed as diverging too much, then why should the expert judgments be privileged over the framework outputs, given that the frameworks themselves were presumably developed by scholars laying claim to domain-relevant expertise? Another purported strategy for validation was to determine the extent to which framework outputs were sensitive to alternative (defensible) analytical choices. Whether this can reasonably be understood as validation is questionable – it is more a question of exploring whether analysis results are sensitive to the choice of a particular analytical method. In other words, it is a form of sensitivity analysis. A final approach to validation adopted by some papers was to use objective measures that, by assumption, correlate with levels of resilience or social vulnerability following a hazardous event. Of the four articles which followed this approach, three relied upon a measure of economic loss as the validation variable. This is ill-founded in our view, as it is well established that the most vulnerability populations will have the least amount of assets to lose in a disaster setting, and so we would not expect a strong correlation between vulnerability (or resilience) and economic loss. More reasonable metrics include mortality, morbidity, and rebuilding timescales, although these measures should be seen as providing *qualitative* corroborations of the frameworks (or identifying discrepancies within them), rather than provide precise quantitative tests.

The clear majority of studies of both resilience and social vulnerability were concerned with mapping out spatial rather than temporal variation in those constructs. This is a significant limitation as resilience, in particular, is broadly conceived of as a dynamic process, which raises questions about the suitability of static measurement approaches (see also Cai et al., 2018). Longitudinal approaches would allow us to learn about the co-evolution of hazards and resilience, and about how the various components of this construct influence each other over time. Another temporal consideration involves forecasting changes in resilience or social vulnerability in future years, for example drawing on demographic projections (see (Hardy and Hauer, 2018). This form of prospective analysis was not undertaken in our selected papers.

### 4.4. Policy-orientation vs. Hypothesis driven studies

A clear majority of our selected papers were concerned with quantifying geographical variations in resilience or social vulnerability. But to what end? The typical claim was that such measurements would be useful for policy or practice, for example in helping prioritise hazard mitigation, emergency response, and recovery efforts. Whether such mapping exercises are actually used by policy makers or practitioners remains an open question. Only 6 of our selected articles were hypothesis driven (section 3.5). What are some open questions that are worth examining in the future? Some relate to environmental justice, i.e. what is the relationship between social vulnerability or resilience and hazard exposure within developing nations, and how is it modified by factors such as hazard type, governance style (e.g. authoritarian vs. clientelistic vs. liberalised), and urban vs. rural? And to what extent is perceived social vulnerability or resilience correlated with

[5] Recall that not only was it the most frequently adopted conceptual framework, but it was also referred to as the point of departure by several articles that we classed as lacking a clear conceptual framework (section 3.2.2)

"objective" measures of those constructs across the Global South (e.g. in risk research there has been a long standing concern with the different concepts of risk held by publics and experts, and on the implications of this for policy and governance)? How do resilience and social vulnerability co-evolve in relation to intermittent shocks such as landslide and debris flow events? How effective are various kinds of policy interventions in changing community vulnerability or resilience in developing nations? Does social capital make a particularly significant contribution to resilience in developing countries, given that they typically only have rudimentary social safety nets and limited formal insurance systems?

## 5. Conclusion

Before reflecting on future research directions, we first restate our findings: (1) A significant number of studies consider resilience and social vulnerability to be generic properties of social systems, in contrast to a view which sees them as being a function of the specific hazards under consideration; (2) Few papers measured changes in vulnerability or resilience over time, which limits our understanding of the extent to which they co-evolve with exogenous factors (e.g. policy interventions, hazardous events); (3) The majority of studies relied on census data. There are natural trade-offs in relying on census rather than survey data, in terms of spatial scale, reliability, and relevance of the data; (4) Many papers were stock applications of existing frameworks, with little adaptation to socio-cultural contexts. Where adaptation occurred, there was often little discussion of the underlying method for doing so; (5) There was a lack of systematic efforts at validation. Where validation was attempted, it was limited in scope or questionable in approach; (6) More hypothesis-driven studies are required in order to develop a better understanding of the drivers of social vulnerability and resilience, along with the mechanisms through which they shape the capacity to plan, respond, and recover from disasters.

Given the above findings, where should the field go next? Below we identify a series of broad but concrete suggestions for improving the measurement of social vulnerability and resilience in developing countries.

We first suggest that the field should abandon the notion of validation. The reason is simple: SoVI, DROP and cognate frameworks make no *quantitative*, testable predictions, so cannot be validated under any meaningful sense of the term. Indeed it is no surprise that purported attempts at validation tend to be poorly conceived and implemented. A more promising approach for the field would be to systematically evaluate dimensions of model quality that go beyond those considered in classical validation tests (i.e. that go beyond the traditional emphasis on predictive accuracy or fit to datasets; MacGillivray and Richards, 2015). Key considerations include: are the underlying assumptions made explicit and defended; does the model-building methodology have sufficient "pedigree;" are parameter and model uncertainties explicitly accounted for (e.g. through sensitivity analysis or ensemble modelling). Many of these quality dimensions are not readily formalised, yet there are structured ways of taking account of them (e.g. van der Sluijs et al., 2005; MacGillivray, 2019; Spiegelhalter and Riesch, 2011).

The second point is that there is a need for a series of reforms if the field is to shift away from a series of largely disconnected, descriptive mapping exercises, towards a field that progressively accumulates empirical findings that support coherent theory-building and inform policy-making. This will require the community to develop shared understandings of basic concepts; adopt explicit, defensible methodologies for implementing generic frameworks in particular cultural, social, political and geographic contexts; provide greater emphasis on the formation and testing of hypotheses (see section 4.4 for some concrete suggestions); and adopt more longitudinal studies as opposed to static analyses. This will require sustained, ambitious investments from research funders, and could be catalysed by the development of Resilience or Vulnerability laboratories, where research, expertise, and tools could be shared, perhaps modelled on the NSF Critical Zone Observatory network. Crucially, such efforts, and any such network, should be co-developed along with potential users of this science.

Although much vulnerability and resilience analyses are motivated by a desire to inform practical decision-making, there is limited evidence, at least within our sample papers, that these desires are realised. More rigorous processes of model building and evaluation; more coherent concepts and theory-building; and greater attention to co-production, can help address this mismatch by increasing the policy-relevance and credibility of the science produced within the field.

## Acknowledgements

This research was supported by a joint Natural Environmental Research Council- National Science Foundation of China Economic and Social Research Council-Newton Fund grant (NERC grant number, NE/N012240/1 and NSFC grant number 4151101239, "Resilience to earthquake-induced landslide hazard in China." Two anonymous reviewers provided helpful comments. The usual caveats remain.

## Appendix A:. Data extraction form

| | Information extracted | Description |
|---|---|---|
| Bibliometric of the selected studies | Study area | Where is the study area (country or region) for the article? |
| | Core concept | What is the core concept or key term that the study measured?<br>• Social vulnerability<br>• Vulnerability<br>• Resilience<br>• Risk<br>• Other |
| Hazard types | Hazard types | Is the vulnerability measurement applied for:<br>• Generic hazards<br>• A specific type of hazard, |

(*continued on next page*)

**Data extraction form** (*continued*)

| | Information extracted | Description |
|---|---|---|
| | | • Multiple hazards |
| Conceptualisation | Definition | How is the concept (vulnerability or resilience) defined? |
| | Conceptual framework | What is the conceptual or theoretical framework behind the measurement? |
| Data and measurement | Geographic Unit | • Nation<br>• Catchment<br>• Province or State<br>• City<br>• County (also includes local government, town, and municipalities)<br>• District (the smallest publicly available statistical unit, village, barangay, and ward)<br>• Small area (such as community and neighbourhood)<br>• Household and individual (including building)<br>• Grid: pixel |
| | Data source | What types of data source were applied?<br>• Census including official statistics<br>• First hand data from survey<br>• A mix of survey and census data<br>• Satellite images<br>• Other |
| | Process from framework to indicators | What is the process or basis for the indicators selected following the framework?<br>How close is the framework related to the selection of indicators?<br>• Very close connection: Mainly theory driven<br>• Close connection: Mix theory and data driven<br>• Very loose connection: Data driven |
| | Analytical approach | What were methods or techniques applied or generate the index or measurement of the key concept? |
| | Validation | Were the results validated? What is the validation method? |
| Adaptation | Framework adaptation | Is the framework adapted for the geographic or cultural context?<br>• No adaptation<br>• Data adaption<br>• Expert views<br>• Incorporate with local knowledge<br>• Explicit cultural adaptation |
| | Weights | Were the indicators or factors weighted equally? If not, how were the weights given? |
| Hypothesis | Hypothesis test | Was there any hypothesis tested in the study? What is it? |

## References


Adger, W.N., Huq, S., Brown, K., Conway, D., Hulme, M., 2003. Adaptation to climate change in the developing world. Progress in Development Studies 3, 179–195.

Ahsan, M.N., Warner, J., 2014. The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks-A case study in the south-western coastal Bangladesh. Int. J. Disaster Risk Reduct. 8, 32–49.

Akter, S., Mallick, B., 2013. The poverty-vulnerability-resilience nexus: Evidence from Bangladesh. Ecol. Econ. 96, 114–124.

Aldrich, D.P., 2012. Building resilience: Social capital in post-disaster recovery. University of Chicago Press.

Aldrich, D.P., Sawada, Y., 2015. The physical and social determinants of mortality in the 3.11 tsunami. Soc. Sci. Med. 124, 66–75.

Ancog, R.C., Rebancos, C.M., Sumalde, Z.M., 2016. Levels and determinants of vulnerability of two indigenous communities in the Philippines Implications from using mixed-methods approach. Int. J. Clim. Change Strategies Manage. 8, 154–174.

Andrade, M.M.N.D., Szlafsztein, C.F., 2018. Vulnerability assessment including tangible and intangible components in the index composition: An Amazon case study of flooding and flash flooding. Sci. Total Environ. 630, 903–912.

Antwi-Agyei, P., Dougill, A.J., Fraser, E.D.G., Stringer, L.C., 2013. Characterising the nature of household vulnerability to climate variability: Empirical evidence from two regions of Ghana. Environ. Dev. Sustain. 15, 903–926.

Asadzadeh, A., Kotter, T., Zebardast, E., 2015. An augmented approach for measurement of disaster resilience using connective factor analysis and analytic network process (F'ANP) model. Int. J. Disaster Risk Reduct. 14, 504–518.

Bakkensen, L.A., Fox-Lent, C., Read, L.K., Linkov, I., 2016. Validating Resilience and Vulnerability Indices in the Context of Natural Disasters. Risk Anal.

Balica, S., Douben, N., Wright, N., 2009. Flood vulnerability indices at varying spatial scales. Water Sci. Technol. 60, 2571–2580.

Bene, C., Al-Hassan, R.M., Amarasinghe, O., Fong, P., Ocran, J., Onumah, E., Ratuniata, R., Tuyen, T.V., McGregor, J.A., Mills, D.J., 2016. Is resilience socially constructed? Empirical evidence from Fiji, Ghana, Sri Lanka, and Vietnam. Global Environmental Change-Human and Policy Dimensions 38, 153–170.

BIRKMANN, E. J. & VAN GINKEL, H. 2006. Measuring vulnerability to natural hazards: Toward disaster resilient societies.

Birkmann, J., Cardona, O. D., Carre O, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P. & Welle, T., 2013. Framing vulnerability, risk and societal responses: the MOVE framework Natural Hazards 67 2013 193 211

Boruff, B., Cutter, S., 2007. The environmental vulnerability of Caribbean island nations. Geogr. Rev. 97, 24–45.

Brink, S.A., Davidson, R.A., 2015. Framework for comprehensive assessment of a city's natural disaster risk. Earthquake Spectra 31, 1931–1947.

Busby, J., Cook, K., Vizy, E., Smith, T., Bekalo, M., 2014. Identifying hot spots of security vulnerability associated with climate change in Africa. Clim. Change 124, 717–731.

Cai, H., Lam, N.S., Qiang, Y., Zou, L., Correll, R.M., Mihunov, V., 2018. A synthesis of disaster resilience measurement methods and indices. Int. J. Disaster Risk Reduct. 31, 844–855.

Chakraborty, A., Joshi, P.K., 2016. Mapping disaster vulnerability in India using analytical hierarchy process. Geomatics Natural Hazards & Risk 7, 308–325.

Chen, W., Cutter, S.L., Emrich, C.T., Shi, P., 2013. Measuring social vulnerability to natural hazards in the Yangtze River Delta region, China. International Journal of Disaster Risk Science 4, 169–181.

Cohen, J., 1968. Weighted kappa: Nominal scale agreement provision for scaled disagreement or partial credit. Psychol. Bull. 70 (4), 213.

Cutter, S.L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., Webb, J., 2008. A place-based model for understanding community resilience to natural disasters. Global Environ. Change 18, 598–606.

Cutter, S.L., Boruff, B.J., Shirley, W.L., 2003. Social Vulnerability to Environmental Hazards*. Social Science Quarterly 84, 242–261.
D.E. Loyola Hummell, B. M., Cutter, S. L., Emrich, C. T., 2016. Social Vulnerability to Natural Hazards in Brazil. Int. J. Disaster Risk Sci., 7, 111-122
de Silva, M.J., Harpham, T., Tuan, T., Bartolini, R., Penny, M.E., Huttly, S.R., 2006. Psychometric and cognitive validation of a social capital measurement tool in Peru and Vietnam. Soc. Sci. Med. 62, 941–953.
Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L. & BL Schl, G., 2015. Debates - Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. Water Resources Research 51, 4770–4781
Ding, M.T., Heiser, M., Hubl, J., Fuchs, S., 2016. Regional vulnerability assessment for debris flows in China-a CWS approach. Landslides 13, 537–550.
Ebert, A., Kerle, N., Stein, A., 2009. Urban social vulnerability assessment with physical proxies and spatial metrics derived from air- and spaceborne imagery and GIS data. Nat. Hazards 48, 275–294.
England, P., Jackson, J., 2011. Uncharted seismic risk. Nat. Geosci. 4 (6), 348.
Fang, C., Wang, Y., Fang, J., 2016. A comprehensive assessment of urban vulnerability and its spatial differentiation in China. J. Geog. Sci. 26, 153–170.
Gainsborough, M., 2007. From patronage to" outcomes": Vietnam's communist party congresses reconsidered. Journal of Vietnamese Studies 2 (1), 3–26.
Gawith, D., Daigneault, A., Brown, P., 2016. Does community resilience mitigate loss and damage from climaterelated disasters? Evidence based on survey data. J. Environ. Plann. Manage. 59, 2102–2123.
Ge, Y., Dou, W., Gu, Z., Qian, X., Wang, J., Xu, W., Shi, P., Ming, X., Zhou, X., Chen, Y., 2013. Assessment of social vulnerability to natural hazards in the Yangtze River Delta, China. Stoch. Env. Res. Risk Assess. 27, 1899–1908.
Gil-Guirado, S., Espin-Sanchez, J.A., Prieto, M.D., 2016. Can we learn from the past? Four hundred years of changes in adaptation to floods and droughts. Measuring the vulnerability in two Hispanic cities. Clim. Change 139, 183–200.
Hagenlocher, M., Renaud, F.G., Haas, S., Sebesvari, Z., 2018. Vulnerability and risk of deltaic social-ecological systems exposed to multiple hazards. Sci. Total Environ. 631–632, 71–80.
Hardy, R.D., Hauer, M.E., 2018. Social vulnerability projections improve sea-level rise risk assessments. Appl. Geogr. 91, 10–20.
Hou, J., Lv, J., Chen, X., Yu, S., 2016. China's regional social vulnerability to geological disasters: evaluation and spatial characteristics analysis. Nat. Hazards 84, 97–111.
Huang, J., Liu, Y., Ma, L., Su, F., 2013. Methodology for the assessment and classification of regional vulnerability to natural hazards in China: the application of a DEA model. Nat. Hazards 65, 115–134.
Huang, J., Su, F., Zhang, P., 2015. Measuring social vulnerability to natural hazards in Beijing-Tianjin-Hebei Region, China. Chinese Geographical Science 25, 472–485.
Huang, R., Fan, X., 2013. The landslide story. Nat. Geosci. 6 (5), 325.
Ignacio, J.A.F., Cruz, G.T., Nardi, F., Henry, S., 2015. Assessing the effectiveness of a social vulnerability index in predicting heterogeneity in the impacts of natural hazards: Case study of the Tropical Storm Washi flood in the Philippines. Vienna Yearbook of Population Research 13, 91.
Inostroza, L., Palme, M., de la Barrera, F., 2016. A Heat Vulnerability Index: Spatial Patterns of Exposure, Sensitivity and Adaptive Capacity for Santiago de Chile. PLoS ONE 11, 26.
Künzler, M., Huggel, C., Ramírez, J.M., 2012. A risk analysis for floods and lahars: case study in the Cordillera Central of Colombia. Natural hazards 64 (1), 767–796.
Kafle, S.K., 2012. Measuring disaster-resilient communities: a case study of coastal communities in Indonesia. Journal of business continuity & emergency Planning 5, 316–326.
Klinenberg, E., 2015. Heat wave: A social autopsy of disaster in Chicago. University of Chicago Press.
Kotzee, I., Reyers, B., 2016. Piloting a social-ecological index for measuring flood resilience: A composite index approach. Ecol. Ind. 60, 45–53.
Kovacevic-Majkic, J., Panic, M., Miljanovic, D., Miletic, R., 2014. Vulnerability to natural disasters in Serbia: spatial and temporal comparison. Nat. Hazards 72, 945–968.
Kusumastuti, R. D., Viverita, Husodo, Z. A., Suardi, L. & Danarsari, D. N. 2014. Developing a resilience index towards natural disasters in Indonesia. Int. J. Disaster Risk Reduction, 10, 327-340
Landis, J.R., Koch, G.G., 1977. The measurement of observer agreement for categorical data. Biometrics 33, 159–174.
Lam, N.S.N., Arenas, H., Brito, P.L., Liu, K.B., 2014. Assessment of vulnerability and adaptive capacity to coastal hazards in the Caribbean Region. J. Coastal Res., 473–478
Lawal, O., Arokoyu, S.B., 2015. Modelling social vulnerability in sub-Saharan West Africa using a geographical information system. Jamba: Journal of Disaster Risk Studies 7, 11.
Lee, Y.-J., 2014. Social vulnerability indicators as a sustainable planning tool. Environ. Impact Assess. Rev. 44, 31–42.
Li, X.L., Wang, L., Liu, S., 2016. Geographical Analysis of Community Resilience to Seismic Hazard in Southwest China. International Journal of Disaster Risk Science 7, 257–276.
Liberati, A., Altman, D.G., Tetzlaff, J., Mulrow, C., Gotzsche, P.C., Ioannidis, J.P.A., Clarke, M., Devereaux, P.J., Kleijnen, J., Moher, D., 2009. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate healthcare interventions: explanation and elaboration. Bmj-British Medical Journal, 339.
Lin, K.H.E., Polsky, C., 2016. Indexing livelihood vulnerability to the effects of typhoons in indigenous communities in Taiwan. Geogr. J. 182, 135–152.
Liu, D., Li, Y., 2016. Social vulnerability of rural households to flood hazards in western mountainous regions of Henan province, China. Nat. Hazards Earth Syst. Sci. 16, 1123–1134.
Lixin, Y., Xi, Z., Lingling, G., Dong, Z., 2014. Analysis of social vulnerability to hazards in China. Environmental Earth Sciences 71, 3109–3117.
Maharani, Y.N., Lee, S., Ki, S.J., 2016. Social vulnerability at a local level around the Merapi volcano. Int. J. Disaster Risk Reduct. 20, 63–77.
Macgillivray, B.H., 2018. Beyond social capital: The norms, belief systems, and agency embedded in social networks shape resilience to climatic and geophysical hazards. Environ. Sci. Policy 89, 116–125.
MacGillivray, B.H., Richards, K., 2015. Approaches to evaluating model quality across different regime types in environmental and public health governance. Global Environ. Change 33, 23–31.
Macgillivray, B.H., 2019. Null hypothesis testing – scientific inference: a critique of the shaky premise at the heart of the science and values debate, and a defense of value-neutral risk assessment. Risk Analys. 39 (7), 1520–1532.
Miao, C., Ding, M., 2015. Social vulnerability assessment of geological hazards based on entropy method in Lushan earthquake-stricken area. Arabian J. Geosci. 8, 10241–10253.
Miller, F., Osbahr, H., Boyd, E., Thomalla, F., Bharawani, S., Ziervogel, G., Walker, B., Birkmann, J., Van Der Leeuw, S. & Rockstr M, J. 2010. Resilience and vulnerability: complementary or conflicting concepts? Ecol. Society, 15, 1-25
Muller, A., Reiter, J., Weiland, U., 2011. Assessment of urban vulnerability towards floods using an indicator-based approach - a case study for Santiago de Chile. Nat. Hazards Earth Syst. Sci. 11, 2107–2123.
Mustafa, D., Ahmed, S., Saroch, E., Bell, H., 2011. Pinning down vulnerability: From narratives to numbers. Disasters 35, 62–86.
Mwale, F.D., Adeloye, A.J., Beevers, L., 2015. Quantifying vulnerability of rural communities to flooding in SSA: A contemporary disaster management perspective applied to the Lower Shire Valley, Malawi. Int. J. Disaster Risk Reduct. 12, 172–187.
Ni, C., Chow, M. C. M., Jiang, X., Li, S. & Pang, S. M. C. 2015. Factors associated with resilience of adult survivors five years after the 2008 Sichuan earthquake in China. PLoS ONE, 10.
Orencio, P.M., Fujii, M., 2013. An Index to Determine Vulnerability of Communities in a Coastal Zone: A Case Study of Baler, Aurora, Philippines. Ambio 42, 61–71.
Pati, R.C., Franco, D.T., Alcantara, A.J., Pacardo, E.P., Resurreccion, A.N., 2014. Vulnerability to Flooding of the Towns of Mabitac and Santa Maria, Laguna, Philippines. Journal of Environmental Science and Management 17, 17–28.
Pelling, M., 2003. Natural disaster and development in a globalizing world. Routledge.
Petticrew, M. 2006. Why Do We Need Systematic Reviews? In: Petticrew, M. & Roberts, H. (eds.) Systematic reviews in the social sciences :A pratical guide. Malden, MA: Blackwell Publishing
Piya, L., Joshi, N.P., Maharjan, K.L., 2016. Vulnerability of Chepang households to climate change and extremes in the Mid-Hills of Nepal. Clim. Change 135, 521–537.
Plummer, R., Crona, B., Armitage, D.R., Olsson, P., Teng, X.F., Maria, Yudina, O., 2012. Adaptive Comanagement a Systematic Review and Analysis. Ecology and Society, 17.
Qasim, S., Qasim, M., Shrestha, R.P., Khan, A.N., Tun, K., Ashraf, M., 2016. Community resilience to flood hazards in Khyber Pukhthunkhwa province of Pakistan. Int. J. Disaster Risk Reduct. 18, 100–106.
Rahman, N., Ansary, M.A., Islam, I., 2015. GIS based mapping of vulnerability to earthquake and fire hazard in Dhaka city, Bangladesh. Int. J. Disaster Risk Reduct. 13, 291–300.
Razafindrabe, B.H., Parvin, G.A., Surjan, A., Shaw, R., 2009. Climate disaster resilience: focus on coastal urban cities in Asia. Asian Journal of environment and disaster Management 1, 1–15.
Rogelis, M.C., Werner, M., Obregon, N., Wright, N., 2016. Regional prioritisation of flood risk in mountainous areas. Nat. Hazards Earth Syst. Sci. 16, 833–853.
Roncancio, D.J., Nardocci, A.C., 2016. Social vulnerability to natural hazards in São Paulo, Brazil. Nat. Hazards 84, 1367–1383.
Rubin, O., 2014. Social vulnerability to climate-induced natural disasters: Cross-provincial evidence from Vietnam. Asia Pacific Viewpoint 55, 67–80.
Rubin, O., 2015. The Burden of Excessive "Linking Social Capital": Evidence from Four Vietnamese Provinces. Asian Journal of Social Science 43 (6), 760–785.
Rufat, S., Tate, E., Burton, C.G., Maroof, A.S., 2015. Social vulnerability to floods: Review of case studies and implications for measurement. Int. J. Disaster Risk Reduct. 14, 470–486.
Sherly, M.A., Karmakar, S., Parthasarathy, D., Chan, T., Rau, C., 2015. Disaster Vulnerability Mapping for a Densely Populated Coastal Urban Area: An Application to Mumbai, India. Ann. Assoc. Am. Geogr. 105, 1198–1220.
Siagian, T.H., Purhadi, P., Suhartono, S., Ritonga, H., 2014. Social vulnerability to natural hazards in Indonesia: Driving factors and policy implications. Nat. Hazards 70, 1603–1617.
Siebeneck, L., Arlikatti, S., Andrew, S.A., 2015. Using provincial baseline indicators to model geographic variations of disaster resilience in Thailand. Nat. Hazards 79, 955–975.
Singh, C., Deshpande, T., Basu, R., 2017. How do we assess vulnerability to climate change in India? A systematic review of literature. Reg. Environ. Change 17, 527–538.
Spiegelhalter, D.J., Riesch, H., 2011. Don't know, can't know: embracing deeper uncertainties when analysing risks. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369 (1956), 4730–4750.

Su, S., Pi, J., Wan, C., Li, H., Xiao, R., Li, B., 2015. Categorizing social vulnerability patterns in Chinese coastal cities. Ocean Coast. Manag. 116, 1–8.
Sudmeier, K.I., Jaboyedoff, M., Jaquet, S., 2013. Operationalizing "resilience" for disaster risk reduction in mountainous Nepal. Disaster Prevention and Management 22, 366–377.
Thompson, R.R., Garfin, D.R., Silver, R.C., 2017. Evacuation from Natural Disasters: A Systematic Review of the Literature. Risk Anal., n/a-n/a
Timmerman, P., 1981. Vulnerability resilience and collapse of society. University of Toronto, Toronto, Canada, Institute for Environmental Studies.
Unisdr, U., 2015. March. Sendai framework for disaster risk reduction 2015–2030. In: In Proceedings of the 3rd United Nations World Conference on DRR, Sendai, Japan, pp. 14–18.
van der Sluijs, J.P., Craye, M., Funtowicz, S., Kloprogge, P., Ravetz, J., Risbey, J., 2005. Combining quantitative and qualitative measures of uncertainty in model-based environmental assessment: the NUSAP system. Risk Anal. 25 (2), 481–492.
Yan, L., Xu, X., 2010. Assessing the vulnerability of social-environmental system from the perspective of hazard, sensitivity, and resilience: A case study of Beijing, China. Environmental Earth Sciences 61, 1179–1186.
Yan, X., Li, X., 2016. Evaluation on social vulnerability to natural disasters. Anthropologist 24, 570–580.
Yang, S., He, S., Du, J., Sun, X., 2015. Screening of social vulnerability to natural hazards in China. Nat. Hazards 76, 1–18.
Yenneti, K., Tripathi, S., Wei, Y.D., Chen, W., Joshi, G., 2016. The truly disadvantaged? Assessing social vulnerability to climate change in urban India. Habitat International 56, 124–135.
Zebardast, E., 2013. Constructing a social vulnerability index to earthquake hazards using a hybrid factor analysis and analytic network process (F'ANP) model. Nat. Hazards 65, 1331–1359.
Zeng, J., Zhu, Z.Y., Zhang, J.L., Ouyang, T.P., Qiu, S.F., Zou, Y., Zeng, T., 2012. Social vulnerability assessment of natural hazards on county-scale using high spatial resolution satellite imagery: A case study in the Luogang district of Guangzhou, South China. Environmental Earth Sciences 65, 173–182.
Zhang, N., Huang, H., 2013. Social vulnerability for public safety: A case study of Beijing, China. Chin. Sci. Bull. 58, 2387–2394.
Zhang, Y.L., You, W.J., 2014. Social vulnerability to floods: A case study of Huaihe River Basin. Nat. Hazards 71, 2113–2125.
Zhou, H., Wan, J., Jia, H., 2010. Resilience to natural hazards: a geographic perspective. Nat. Hazards 53, 21–41.
Zhou, Y., Li, N., Wu, W., Wu, J., 2014a. Assessment of provincial social vulnerability to natural disasters in China. Nat. Hazards 71, 2165–2186.
Zhou, Y., Li, N., Wu, W., Wu, J., Shi, P., 2014b. Local spatial and temporal factors influencing population and societal vulnerability to natural disasters. Risk Anal. 34, 614–639.
Zhou, Y., Liu, Y.S., Wu, W.X., Li, N., 2015. Integrated risk assessment of multi-hazards in China. Nat. Hazards 78, 257–280.
Zou, L.L., 2012. The impacting factors of vulnerability to natural hazards in China: an analysis based on structural equation model. Nat. Hazards 62, 57–70.